CHAPTER 6

PRECISE MEASUREMENT SYSTEMS

Section I. Types of Measurement

6-1. Purpose. Bending, tilting, and displacement of concrete structures may be detected by measuring changes in horizontal alignment and vertical deflection of their separate parts. Measurement of the position of dam monoliths at six-month intervals over a period of several years provides an indication of the net magnitude of elastic or inelastic deformations that occur in the structure and its foundation. Twisting of side hill blocks and excessive variations in foundation deformations may be detected. All of these types of data are valuable as an indication of the stability of the structure, and furnish information in regard to the correctness and validity of the various design assumptions and analytical procedures.

a. The measurement techniques described in this chapter represent the present technology in the field of precise determination of lengths, angles, and alignments. The instruments include optical, laser, and wavelength techniques to provide alignment, distance measurement, and minute movement to very high degrees of accuracy.

b. On dams and similar structures these techniques require setting up permanent and movable monuments as reference points for using the instruments and targets. Permanent marker points are set in the top and the toe of structures, and length, alignment and deflection readings are made with the precise instruments set up on these monuments. Readings from the electronic instruments that relate to distance measurement are generally accurate to 0.01 ft while alignment measured with the use of micrometer targets are recorded to the nearest 0.001 in., and are usually made at night to avoid troublesome optical distortions due to sunlight and heat radiation.

6-2. Types of Measurement. The types of measurement described in this paragraph fall into three categories, precise alignment instruments, precise distance measuring instruments, and triangulation and trilateration surveys, depending upon their purpose and method of operation. Their installation and operation procedures will be described in more detail in Sections II-IV of this chapter.

a. Precise Alignment Instruments. These instruments function by establishing a precise reference line described by the instrument and the measurement of the distance between markers on the structure and this precise reference line.

(1) Laser Alignment Instruments. This type of instrument is best suited for finding deflections of structures perpendicular to a base line along the length of the structure such as lock wall deflections or dam deflections due to changes in pool elevation.

(2) Theodolite Alignment. This measurement system is similar to the laser alignment system in that it also measures deflections from a base line, however, it uses conventional high precision theodolites and optical targets and has a shorter maximum range than the laser measurement system.

(3) Precise Leveling. This method of measurement uses precise levels and rods to measure change of elevation from a previously established elevation.

b. Precise Distance Measuring. This type of measuring technique utilizes the measurement of the time that it takes a wave of light to travel from its source to a reflector and back to the source. Since the speed of the light wave can be accurately measured and corrected for various conditions of atmospheric density, the distance from source to target is a function of the time it requires the light beam to travel the course. The instrument used for this measurement is the Electronic Distance Measuring (EDM) instrument. This type of precision measurement is made to accurately determine the distance between a reference monument and an alignment marker. Used in its primary capacity it will accurately measure distance, however, when it is used in triangulation and trilateration surveys it will measure deflection of alignment markers.

c. Triangulation and Trilateration Surveys. These methods of precise measurement utilize theories and equations of geometry to transform linear and angular measurements into deflections of alignment points.

(1) Triangulation. This is a method of measurement where deflection of alignment markers is determined by measurement of a base line and the angles associated with the three sides necessary to describe a triangle. This system works well to measure deflections of points on a structure with a curved longitudinal axis. It does not measure vertical deflection well unless the base line and angles measured are in a vertical plane.

(2) Trilateration. This method of measurement determines deflection of points on a structure by successive measurements of the lengths of lines necessary to construct a triangle. It uses the trigonometric principles of angle calculation from known lengths of the sides of triangles to determine the location at points on a structure. It can be used on structures with straight or curved axes and will measure vertical deflection if the measured triangles are in a vertical plane.

Section II. Precise Alignment Instruments

6-3. Laser Alignment Instruments.

a. Description of the Instrument. The laser system consists of a two-component unit of a transmitter and a receiver. The transmitter shown in Figure 6-1 developed by the U. S. Army Engineer Topographic Laboratory, is a continuous-wave helium-neon gas laser, mounted in a yoke, which is similar to the standards of a theodolite, with elevation and azimuth adjustments. The laser mount is attached to a Wild T-2 tribrach which has a built-in circular level and optical plummet for centering on a reference point. The laser exciter is a separate unit and can be operated by either 12-v dc or 115-v ac current. The laser transmitter is equipped with a 2.0-in. beam expanding telescope to provide the necessary degree of collimation.

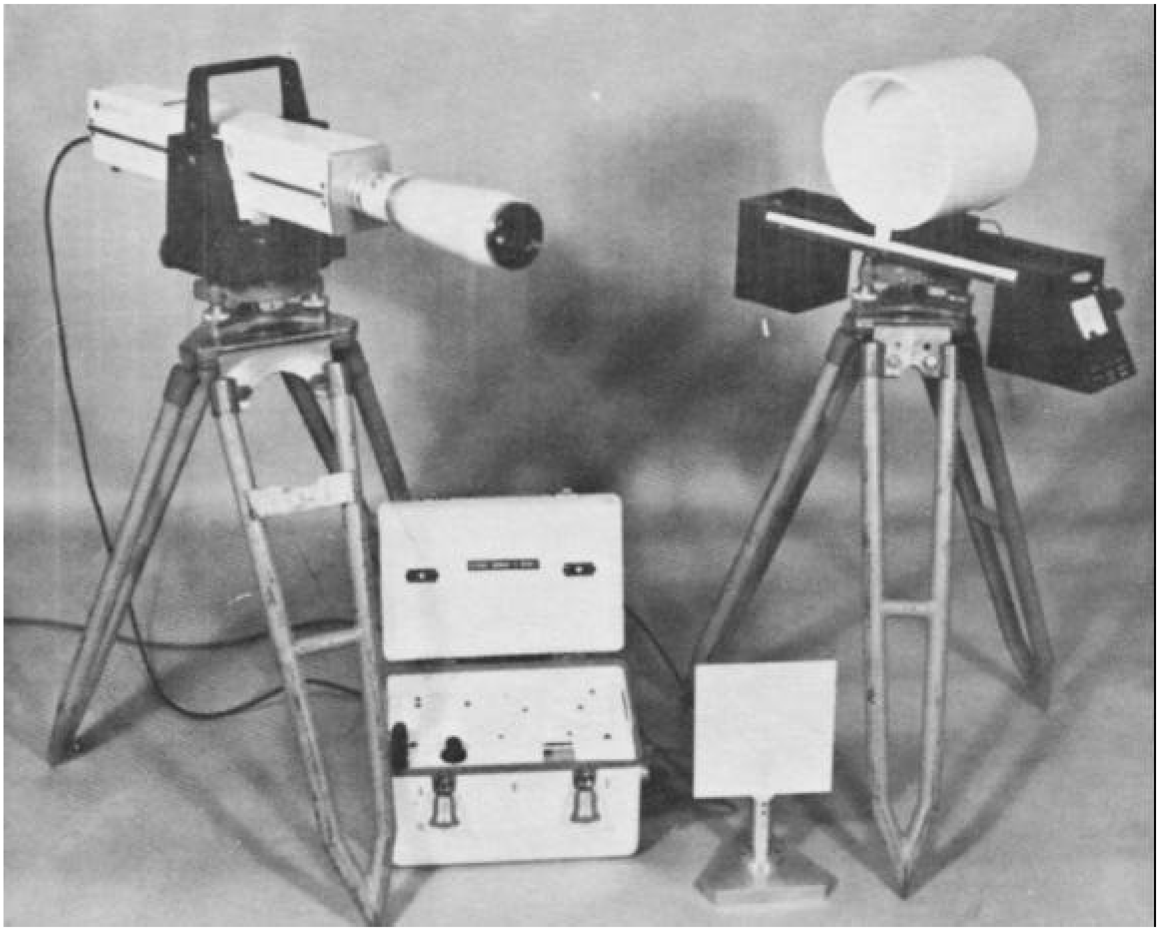


Figure 6-1. Laser Transmitter, Power Source, Alignment Target, and Receiver. (Courtesy of Engineer Topographic Laboratories)

b. Receiver. The fixed target used with a laser is called a receiver. The receiver is basically a short cylinder mounted horizontally, with a vertical divider separating the cylinder into two equal chambers. A lucite diffusion plate covers the receiving end of the cylinder, and a cadmium sulfide photoconductive cell mounted in each chamber measure the amount of light received. The receiver is wired through a Wheatstone bridge circuit to a 50-0-50 microamp meter for readout. Four damping elements in the circuit provide adjustable damping for meter stability. The receiving chamber is mounted on a dovetail slide base assembly which is, in turn, mounted on a Wild T-2 tribrach with built-in circular level and optical plummet. Movement of the receiving chamber is accomplished by an endless cable on the base. Measurement is made on a metric scale fixed to the base and externally lighted for reading ease. Reading is direct to 1 mm and interpolation can be made to 0.1 mm.

6-4. Instrument Installation. Precise laser alignment measuring is accomplished by establishing a straight base line between reference points preferably beyond the structure, and the measurement of the points on the monolith along the base line at periodic intervals. The measurements obtained are an indication of the net magnitude of elastic and inelastic deformations that occur in the structure and its foundation.

a. Location of Reference Monuments. The location of the reference monuments and monolith marker points should be established along the proposed base line as shown in Figure 6-2. The base line should be located so that at completion of construction the line of sight between the reference monuments is unobstructed. Also, consideration should be given to location based on least interference from other operations during alignment measurements. The reference monuments should be located off the structure a sufficient distance not to be influenced by movement of the structure. In instances where this is impractical, the first marker point at each end of the structure may be used as reference points providing the end blocks have low and level foundations. The reference monument elevation should be the least practical vertical height above the structure to maintain the least angle between the precision instrument and monolith marker points. Normally two marker points will be installed on each side of a vertical joint between monoliths. An overall plan and a section between reference monuments and first marker point on the structure should be part of the design submission.

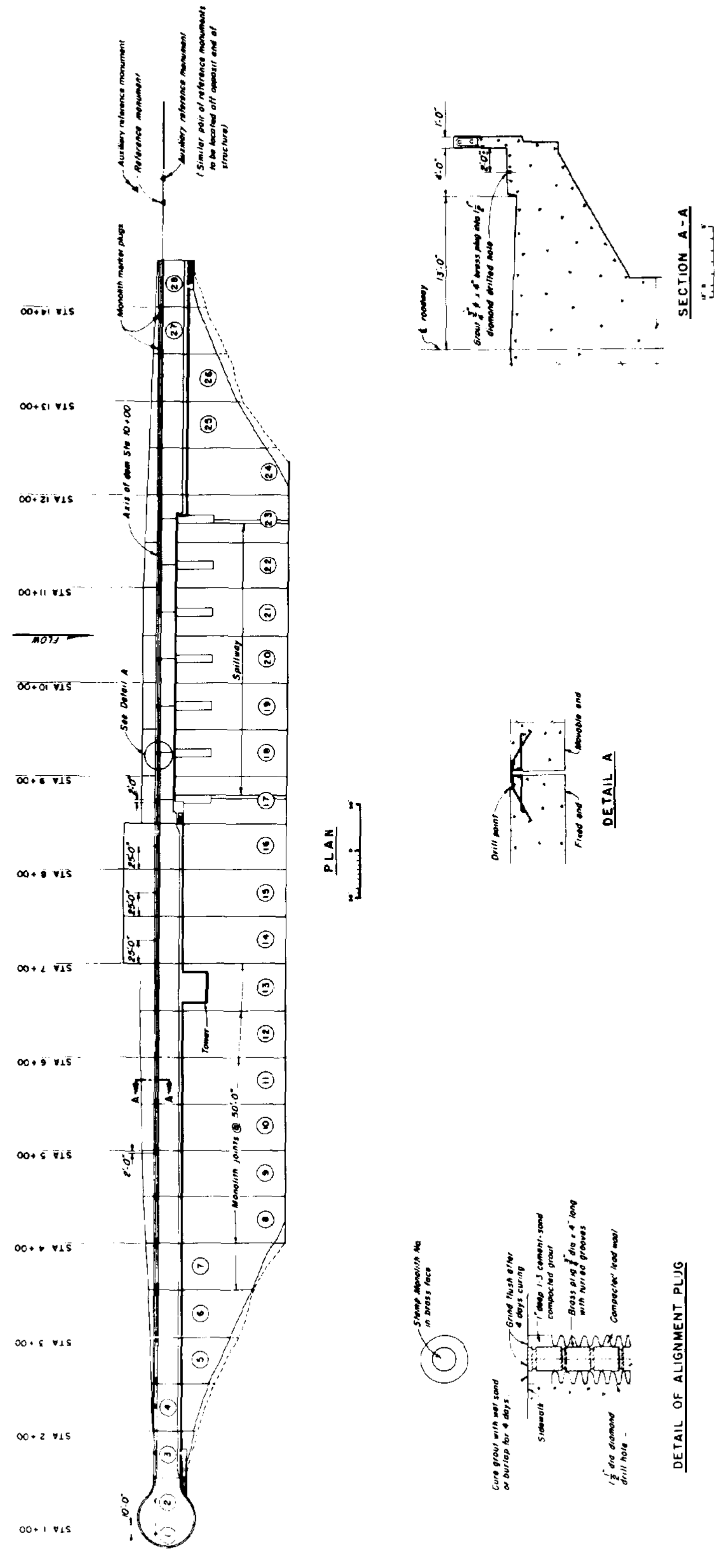


Figure 6-2. Example of Precise Alignment Layout. (Prepared by CE-WES)

b. Monolith Marker Plugs. The brass tablet and brass plugs should be installed by a government survey party. The reference monuments and holes for marker plugs may be installed by the contractor but coordination between contractor and government forces is necessary. If installation is in a new structure, the markers may be set in the fresh concrete; if the installation is in an existing structure, holes must first be drilled in the concrete and then filled with a non-shrink grout and the markers set in the fresh grout.

c. Transmitter. In use, the laser transmitter is placed approximately in line with the monuments and at least 3 ft beyond the end point of the marker line. The laser beam is then directed to strike a reflection target mounted at a corresponding position beyond the other end of the line. The distance between each monument and the source of the laser beam is then measured with the centering detector. Finally, the distance between monuments is measured with a tape. These distance measurements need only to have an accuracy of about one part in 300 and under normal circumstances, need not be repeated during future alignments. Final calculations of alignment may be made with a slide rule.

6-5. Data Collection. During data collection several precautions should be taken to assure good readings. If conditions are subject to gusts of wind, the instrument should be shielded to prevent movement due to high wind forces. Since the stability of the laser beam is directly proportional to the stability of ambient atmospheric conditions, it is recommended that two receivers be used in a survey, one placed at the end point and one placed at the intermediate reading point. As a measurement is made on the intermediate point, one would be made on the end point to measure the beam refraction at that time. Then the appropriate portion of the change could be applied to the measurement taken at the intermediate point. At each point between the two end points, the perpendicular distance from the marker to the reference line is recorded.

6-6. Data Reduction. The data for each monument are read by the instrument monitor and recorded on a field data sheet similar to the one shown in Plate 6-1. When data have been taken for each monument, including the two end point monuments, calculations may be made in the field with a slide rule. The distance between the first and last reading of the alignment network shows how much the markers are out of parallel with the laser beam. By linear proportioning, this difference can be distributed to each of the intermediate points in the network. These adjustments are then subtracted from the raw readings at each intermediate point to get the adjusted reading. If the data are reduced in the field, the data sheet shown can be used and, when completed, sent to the district office. A modified version of this sheet showing only the raw readings, the adjustment, and the distance between the first and last monument can be completed in the field and sent to the district office where the remaining data reduction will be completed.

6-7. Theodolite Alignment Instruments.

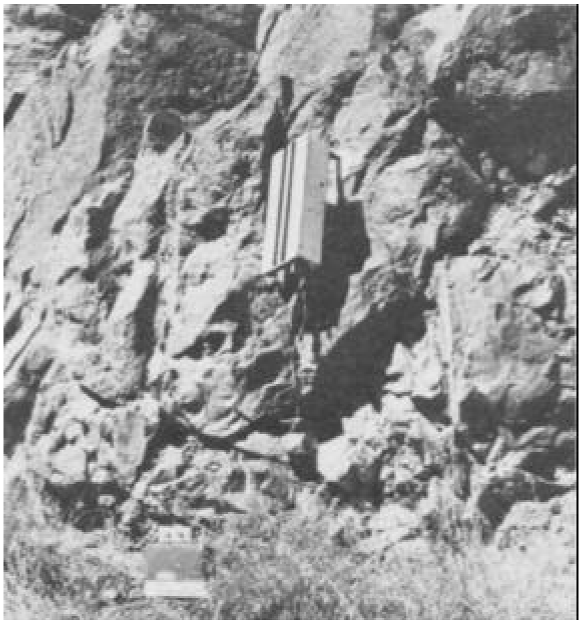
a. Description of the Instrument. The alignment of structures using the theodolite requires the precision theodolite, reference monument, monolith alignment markers, stationary line-of-sight target, and movable micrometer targets.

b. Precision Theodolite. The theodolite should be one of the precision theodolites capable of at least 30 times magnification. Two such instruments, the Wild T2 and F. W. Breithaupt and Sohn "TEAUT," satisfy these requirements. The eyepiece should contain stadia cross hairs with at least one set of double parallel hairs so that the fixed and movable targets may be more accurately viewed and centered. It is preferred that the instrument be equipped with an optical plummet for centering the instrument over the reference monument; however, a conventional plumb bob or other accurate centering device may be used.

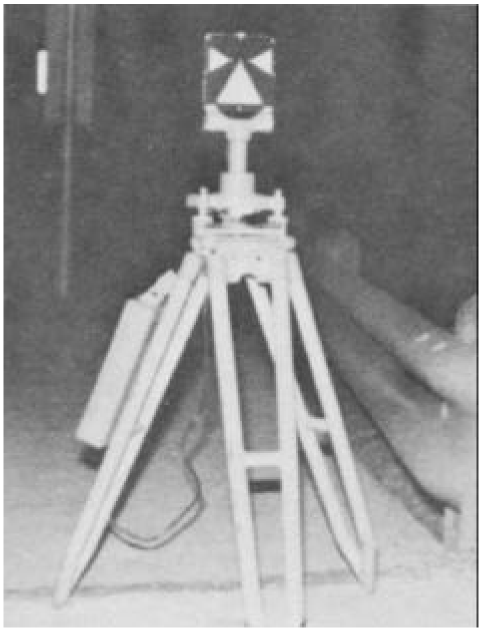
c. Reference Monument. A stainless steel or brass base plate embedded in a concrete monument, which is set on rock or otherwise rigidly fixed, forms the permanent end bench mark. The base plate and the entire monument should be protected by a large diameter concrete pipe and cover. A second auxiliary monument at each end of the dam, set in line with the two principal monuments, will permit recovery of the initial line of sight should a monument be disturbed during construction or maintenance operations.

d. Monolith Marker Points. Single marker points, 3/4-in. diameter brass plugs embedded in the walkway or roadway are normally located on the center line of the dam monoliths. Where two points are placed in a monolith, one should be located adjacent to a bulkhead joint and the other adjacent to the opposite joint.

e. Stationary Line-of-Sight Targets. The distant or fixed targets shown in Figure 6-3 are used in establishing the base line. They are self-lighted targets that are commercially available. The target shown in Figure 6-3.a. is of the type that is rigidly mounted in anchors at the end of the sighting line, and that shown in Figure 6-3.b. is a tripod mounted target that is plummed over a reference monument when there are no permanent anchor points available such that a target as shown in 6-3.a. can be used. Both targets are back-lighted and can be run by 12-volt battery jacks when conventional line current is not available.



a. Rigidly-mounted target.



b. Tripod-mounted target.

Figure 6-3. Stationary Line-of-Sight Targets. (Photos by WES)

f. Movable Targets. Two general types of target are available.

(1) The tripod mounted type is shown in Figure 6-4. It consists of a T-shaped tripod in which two of the legs of the tripod are equipped with leveling screws and the third leg, directly beneath the target, fits into a center punch in the alignment marker described in subparagraph d. of this paragraph. The tripod has two perpendicular bubble levels for leveling the target. The target consists of the target plate inserted in a wide mouth vernier caliper. A standard micrometer anvil with vernier readings to 0.001 in. is provided with a recoil spring along the line of vernier travel to facilitate adjustment of the target plate.

(2) The second type of target, shown in Figure 6-5, screws into a tapped plug embedded in the monolith. It consists of a target mounted in a sliding track that is controlled by a micrometer. The target is moved perpendicular to the line-of-sight until it aligns with the stadia hairs of the theodolite, at which time the micrometer is read and data recorded.

(3) Both targets can be illuminated by a portable lamp reflected off the target for measurement made at night, while the second type can also be lit internally.

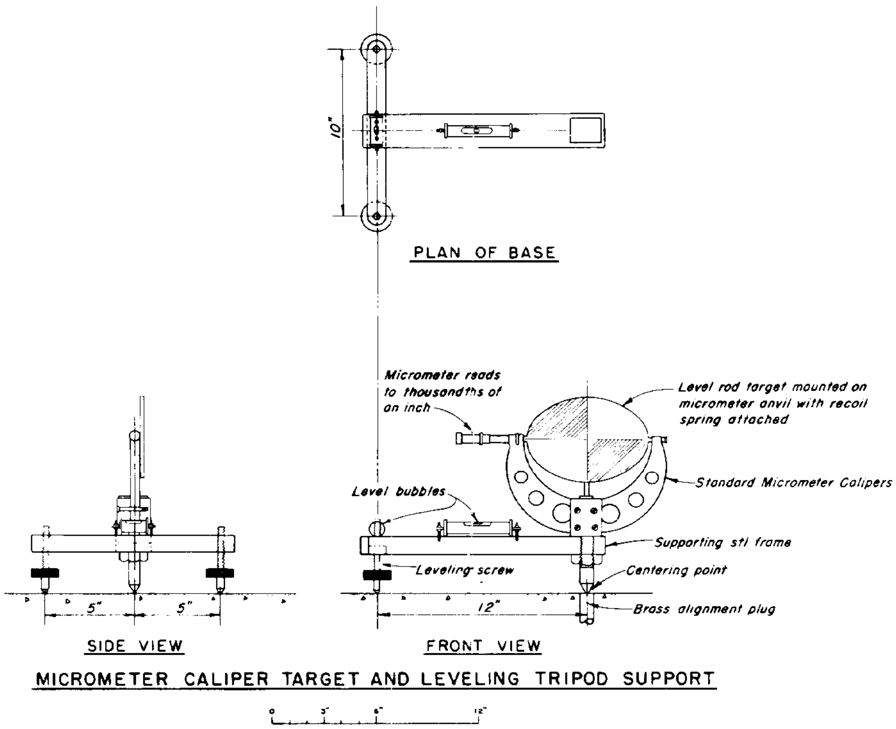


Figure 6-4. Micrometer Caliper Target and Leveling Tripod Support. (Prepared by WES)

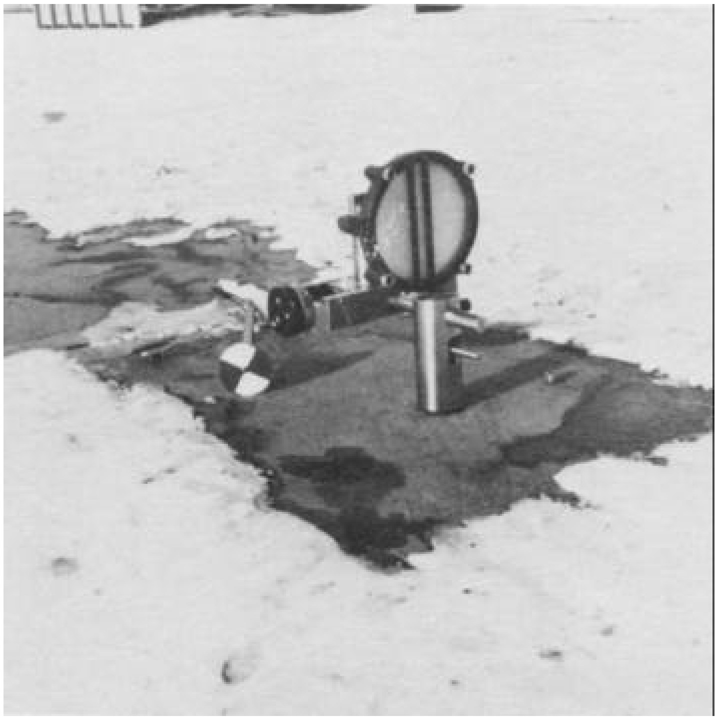


Figure 6-5. Inserted Micrometer Alignment Target. (Photo by WES)

g. Points on Tangent. Points on tangent between the ends of the dam that are occupied by the theodolite may be established using the device shown in Figure 6-6. The device consists of a heavy steel plate supported by three leveling screws. A movable steel plate controlled by a slow motion screw and having a tapered hole into which a special sighting pin or target is inserted permits aligning the tapered hole on line where it may be clamped in position. When a plumb bob or optical centering device is used on the theodolite, the target of the point-on-tangent device may be replaced with a center punched pin.

6-8. Instrument Installation.

a. Reference Monuments. These monuments are used as the reference points for the theodolite in alignment measurements, and for the theodolite and the Electronic Measuring equipment used in triangulation and trilateration described later in this chapter.

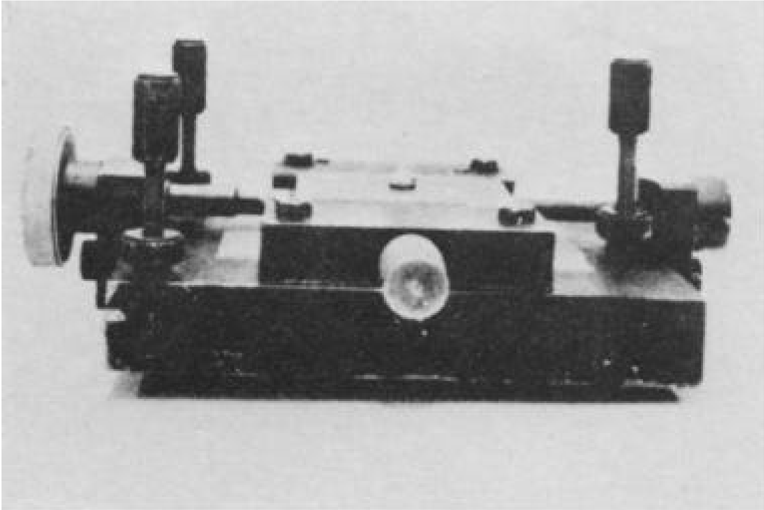


Figure 6-6. Point on Tangent Device with Removable Sighting Pin. (Photo by WES)

(1) Erection of the permanent reference monuments is usually accomplished late in the construction period to reduce the possibility of accidental disturbances of the embedded posts by heavy equipment. Since they are expected to be the reference base for all subsequent measurements, they must be installed such that they will not move with respect to their foundation. A suggested detail for this type of monument is shown in Figure 6-7. It should be used for systems on large structures using triangulation or trilateration and for other locations where precise surveys are made. The monument consists of two concentrically located casings. The inner casing is filled with concrete and the two are grouted together below the ground level. The inner casings acts as the base for the instrument mounting. As shown in Figure 6-7, the monument should be installed at least 10 ft into foundation rock; however, where no solid rock is located near the surface, it should be anchored in solid material.

(2) Auxiliary monuments of similar construction should be installed in line with the primary monuments and to the outside of the monuments such that they can be used to reset any disturbed primary monuments. The reference points should be brass plugs set in concrete, slightly below grade and protected by a large diameter concrete pipe with cover.

(3) A base plate that is compatible with the instrument to be used should be grouted into the top of the monument. This plate makes it possible to mount the instrument in the same orientation and height every time it is to be used. Fastening devices should be cast into the monuments such that a protective cover can be locked over the monument when it is not in use.

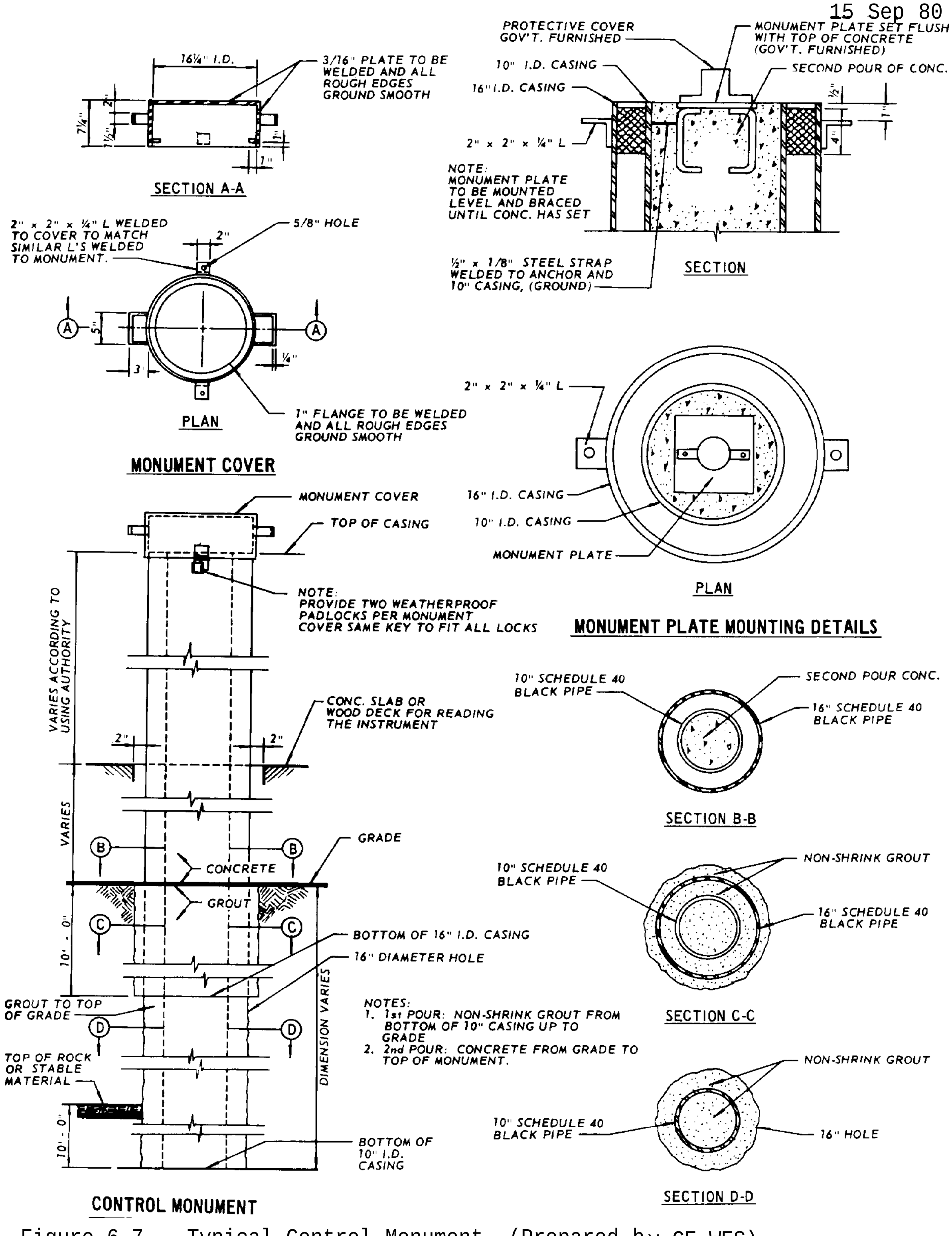


Figure 6-7. Typical Control Monument. (Prepared by CE-WES)

(4) A 6-in. thick concrete pad or wooden deck of sufficient area to provide a good platform on which the survey party can stand should be provided around the base of the monument. The pad should be free of the monument such that any movement of the pad will not affect the monument.

b. Monolith Alignment Markers. The marker points between the end reference monuments are 3/4-in. diameter brass plugs set in the concrete as shown in Figure 6-8. Two types of plugs have been used. One is solid and the initial point on the line is carefully punched or scratch marked in the top. The other type is drilled and tapped with a protective plug screwed in the top. Any markers located in traffic ways should be placed in a small recess in the concrete and protected by a cover. The target-micrometer device for the first type rests on the concrete surface or is tripod-mounted, and the device for the second type screws into the insert.

(1) An ordinary transit is centered over one end reference mark, sighted on the opposite end mark, and the locations of the intermediate monolith marker points spotted on or near this line of sight. The markers should be installed on the structure at the points that would be most likely to experience the greatest or most frequent movement. Consideration should be given to the reservoir water load, and season of the year, when locating the position of the marker plugs in order that subsequent deformations of the structure will not exceed the range or limit of movement of the target-micrometer device. In the case of a lock or dam the most logical location for the alignment markers would be at the high points along the lock or crest of the dam to monitor deflections due to changes in water elevation on the dam or the movement of the monoliths due to filling and emptying of the lock chamber.

(2) The installation should insure that the marker doesn't move with respect to the monolith that it is referencing. In new structures it can be installed at the time of casting the structure, and in older structures a hole in the structure should be drilled and grouted, and the marker set into the fresh grout.

c. Theodolite. The instrument should be set on the base plate of the reference monument, or if no reference monument is used, it should be mounted on a low rigid tripod so that the eyepiece is not more than about 2 ft above the reference marker to facilitate centering the instrument accurately over the marker. It is preferred that the instrument be equipped with an optical plummet for alignment over the marker, but a plumb line is considered accurate.

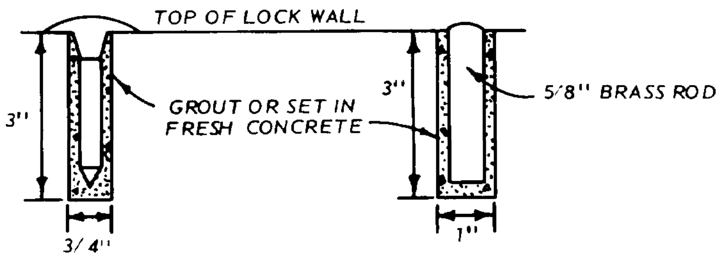


Figure 6-8. Monolith Alignment Markers. (Prepared by WES)

d. Fixed Target. The distant or fixed target is set and remains in the same position throughout each alignment survey as one end of the base line. The target is usually placed at the base line reference monument, but on some sites might be mounted on the extended base line in rock at a vertical abutment. The target should be internally lighted. Where an electrical outlet for operating a fixed lamp is not conveniently available, a battery powered lighting fixture of adequate intensity must be adapted to the target assembly.

e. Movable Targets. The movable target is set over the alignment points in the survey such that the target on the instrument lies in a plane perpendicular to the line-of-sight between the theodolite and the fixed target. This procedure is intended to insure that the target is set up the same each time it is read. The instrument is leveled by the use of the adjustment screws in the legs of the target shown in Figure 6-4, and if a target instrument similar to that shown in Figure 6-5 is used, the instrument is screwed into the alignment point. The alignment point must be installed in the monolith such that when inserted, the instrument will be level.

6-9. Data Collection

a. Observation Procedures. Readings shall be performed at night to avoid troublesome optical distortions due to sunlight and heat radiation. Under some circumstances the readings may take two nights to complete. Since it is recommended that readings be taken at night, the theodolite should have illuminating attachments to make reading the horizontal and vertical circles possible in darkness.

(1) The theodolite is sighted on the fixed target at the far end of the points to be aligned. This sighting is referred to as the line-of-sight. The movable target is placed over or screwed into a marker plug and moved to coincide with the line-of-sight. Four readings of the vernier calipers are obtained for each sighting, two by moving the target into the line-of-sight from the right and two from the left. Four additional readings are obtained when using a theodolite with the telescope in an inverted position. The target caliper readings at each marker plug are recorded on field data sheets, as shown in Plate 6-2. Obviously erroneous readings are discarded, and replaced by supplementary observations.

(2) A general rule should be established requiring the tripod legs to be placed consistently on either the upstream or downstream side of the monolith marker plugs and all sightings to be made from the same end monument so far as practicable in order to avoid error in establishing the direction of measured incremental movements.

b. Reading Schedule. A complete set of observations should be made twice annually, at nearly the same dates each year, one reading in the summer, the other during the winter season. In addition, a third set of observations should be made during periods of unusually high reservoir level. The initial observation should be made prior to the initial filling of the reservoir if possible, in order to record the effect of the first water load against the structure. After three years' records have been obtained, the results should be examined to determine the necessity or desirability of continuing or altering the program.

c. Supplementary Data. A continuous record of reservoir and tailwater elevations will be required. Average monthly air temperatures, preferably from a U. S. Weather Bureau or Corps of Engineers station, frequently will be found valuable in evaluating the precise alignment data or in accounting for possible discrepancies in the results.

6-10. Data Reduction.

a. Field Data Sheets. The eight target caliper readings at each monolith marker plug are recorded on field data sheets for each set of observations. The arithmetic average of the eight values at each plug is computed and entered directly on the field sheet.

b. Processing of Data. Since the true shape of the deflected structure at any given time is rarely known, it is customary to consider the initial measured position as being a straight line. The initial reading values are assumed to be zero, and the incremental changes in alignment are computed by simply subtracting subsequent readings from the initial readings for each monolith marker. A tabular record form is ideally suited for the processing and presentation of the collected data.

c. Presentation of Results. The data reduction procedure, while entirely valid arithmetically, frequently produces apparent deformations that are misleading as to the deflected position of the structure, depending upon the conditions at the time of the initial observations. When the intial survey is made during the coldest of the winter months, most if not all subsequent readings will indicate deflections in an upstream direction. Conversely, an initial survey during a hot summer month will result in downstream deflections during all other times of the year. If the reservoir elevation is comparatively high at the time of the initial survey, subsequent observations during similar seasons with lower reservoir elevations will indicate an upstream deformation. Finally, the initial survey is usually made after the concrete structure has lost some of its heat of hydration but prior to the attainment of final stable temperature conditions; thus the movements observed include only a portion of the permanent temperature readjustment effects. After several surveys have been obtained it may be possible to arrange the results so as to present a more realistic or logical movement history by selecting one of the intermediate surveys to represent the initial or zero condition, and all other deformation readings referred to this base position. A graphical schematic diagram, as shown in Plate 6-3, should be prepared to present the collected precise alignment data. Results of several surveys may be shown on a single sheet.

6-11. Precise Leveling.

a. Description of the Instrument. The level should be of the type designed for accurate geodetic leveling capable of reading vertical elevations to 0.001 m similar to the Wild N-3 level. It should contain a reticle with stadia hairs of 1:100, conventional or split-bubble leveling device, and tripod leveling screws. Object magnification should be greater than 30x for easy readability at long distances.

b. Rod. The level rod should have gradations of 0.01 ft and a micrometer target for readings to 0.001 ft or 1 mm. The rod should be equipped with a centering point that can be attached to its base such that the alignment markers inserted in the top face of locks and dams can also be used for settlement purposes. Care should be taken so that the centering point does not make the level rod readings inaccurate. A bubble level is also required to aid in keeping the rod vertical.

c. Reading Markers. The location of permanent bench markers should be established during design, and survey markers should be located on the structure. These survey markers can coincide with monolith alignment markers.

6-12. Data Collection. Surveys should be performed annually to determine movement of the structure. The first survey elevations should be established as the base elevations. Subsequent surveys should be recorded and compared to the base elevations for overall movement, and to the previous survey for relative movement of the structure.

6-13. Data Reduction. The results of each survey can be reduced to a graphical plot of settlement versus location of data point on the structure by considering the initial survey elevations to be a zero line and plotting the difference between the subsequent surveys and the original survey, as shown in Figure 6-9. An alternate method to record successive surveys is to compute the difference between successive surveys and plot this difference relative to the displacement of the previous survey.

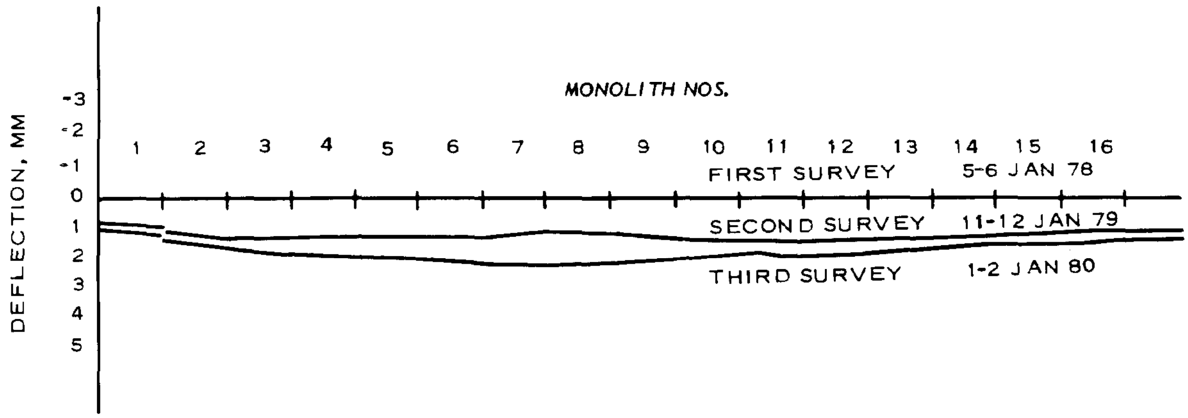


Figure 6-9. Deflection History of Precise Level Survey. (Prepared by WES)

Section III. Precise Distance Measuring Instruments

6-14. Electronic Distance Measurement (EDM) Instruments.

a. Description of the Instrument. EDM's consist of a source instrument, which is also the readout portion of the instrument, a reflector prism assembly, and reference monuments.

b. EDM Source. All modern EDM instruments measure distance by timing, in an indirect fashion, how long it takes light to travel from a source to a reflector and back. By knowing the velocity of light, the distance from the source to the reflector may be calculated. This method of measurement can be used to increase accuracy and decrease time consumption in measurement when compared to the old-fashioned method of taping distances. Depending upon the instrument, resolutions as fine as 0.001 ft can be made by this method of measurement; however, precise frequencies used to modulate the light source and phase comparisons introduce errors into the measurement that need to be compensated.

c. Range. The source instruments should have a range of at least 2 miles and provide least readings of 0.001 m. They should be lightweight for movement around control networks and capable of working from a 12-v battery source for at least 4 hr of normal use without recharge. They should be installed either on the base plate of the reference monuments or set up on tripods and plumbed or optically plumbed to the monument.

d. EDM Prisms. These prisms are used at the alignment marker or reference monument to return the light source to the EDM. Various makes are available; it is recommended that prisms manufactured by the maker of the EDM equipment be used to be compatible with the reading instrument. Figure 6-10 shows some typical prism configurations. Due to the spread of light being proportional to the distance from the light source, the longer the distance being measured the greater number of prisms that are required to reflect the light.

e. Reference Monuments. The reference monuments used are the same as described in paragraphs 6-7c and 6-8a.

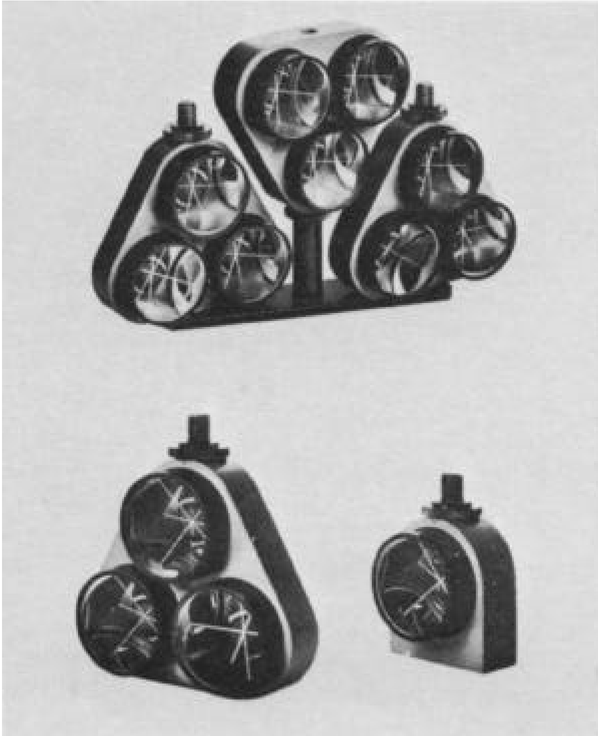


Figure 6-10. EDM Prism Assemblies.(Photo by WES)

6-15. Instrument Installation. The EDM instrument and reflector are set up on the reference markers between which the desired distance is to be measured. Both the instrument and reflector are plumbed over their respective markers and a raw distance is read from the EDM instrument. The path between instrument and reflector should be chosen such that the atmospheric conditions along the length to be measured are the same. If this cannot be accomplished, then the temperature and pressure should be recorded at both the instrument and the reflector and the temperature and pressure information recorded as the average.

6-16. Data Collection. The EDM instrument should be read at least five times and each value of the distance recorded for every measurement from source to reflector. This is done in order to get a good average for the raw reading. The reading of the instrument should be done in accordance with the manufacturer's recommendations. A typical data sheet for one measurement is shown in Figure 6-11.

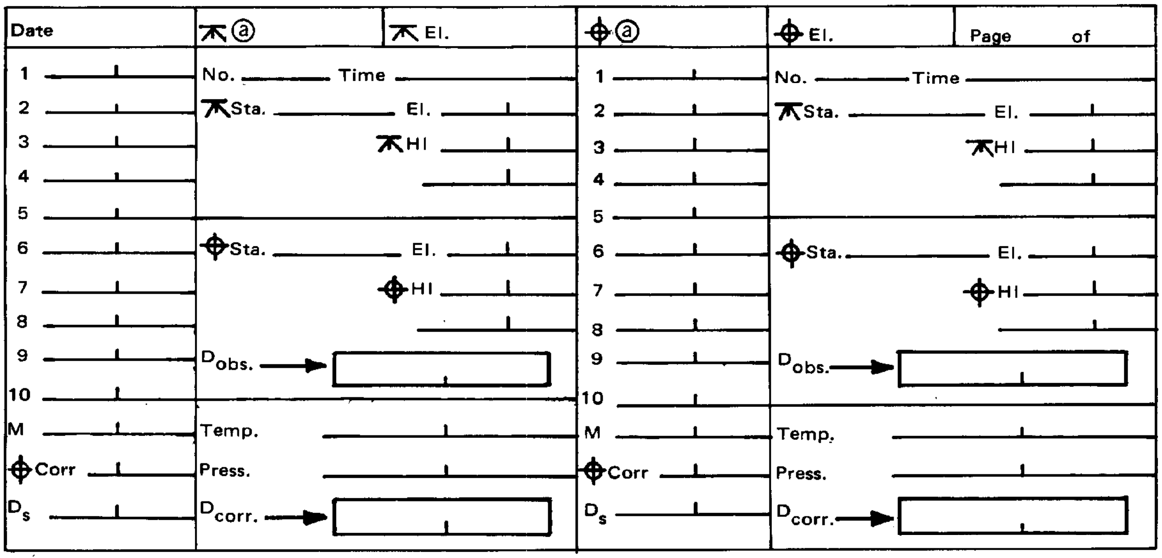


Figure 6-11. Field Data Sheet for EDM Instrument. (Prepared by WES)

6-17. Data Reduction. The mean of the five raw readings is recorded on the line marked M in Figure 6-11. Each reflector has a correction factor that must be applied to the mean of the raw readings to take into account the errors that are due to the reflection of the light wave and the condition that arises when the reflector prism is not directly over the plumbed monument. This correction is either added to or subtracted from the mean to give D_s. The corrected mean distance is then corrected to the spheroid distannce D_{obs} and finally D_{obs} is corrected for temperature and pressure to D_{corr}. Throughout the calculations the station and elevation of the monuments for both the EDM instrument and the reflecting prisms should be kept as well as the height of the instruments and the temperature and pressure at the time of the readings .

Section IV. Triangulation and Trilateration

6-18. Triangulation.

a. General. The face of massive concrete structures such as arch dams is in continuous motion since it undergoes movement as a combined action of temperature fluctuations in the external medium, hydrostatic pressure, and other fluctuating loads. By measuring the changes of coordinate location of each deflection point on the dam, a displacement pattern at each point in each horizontal line of points and each vertical line of points will be determined. A triangulation system consists of a grid pattern of a number of points or targets on the downstream face of the structure and on the foundations along the abutments. The target locations will be charted periodically by observations from a system of theodolite piers downstream of the structure using precise first-order triangulation surveying methods.

b. Description of the Instrument. The equipment necessary to perform a first-order triangulation survey consists of a theodolite of sufficient accuracy with auxiliary equipment from the theodolite manufacturer, reference monuments and deflection targets, and either precise taping equipment or electronic distance measuring equipment,

(1) The description of the theodolite has been previously given in paragraph 6-7a and the description of the Electronic Distance Measuring Equipment in paragraphs 6-14a and b.

(2) The reference monuments and deflection targets should be installed by the contractor during construction. The monuments should be 16 in. in diameter concentrically located, concrete filled metal pipes, and grouted into the foundation rock or stable soil. Access to monument location and suitable platforms should be constructed at monument locations. A brass plate of dimensions compatible with the instrument should be mounted onto the top of the monument to support the theodolite or EDM. Provisions should be made for covering the base plate for protection against weather or accidental damage. Details of these plates are available from theodolite manufacturers. The targets should be installed at specified locations by the contractor. The selection and details of theodolite targets are a design consideration based on site layout from the piers. Field trials and observations of various type targets should be accomplished during design.

6-19. Instrument Installation.

a. Monuments. The theodolite monuments should be located so that a network of quadralaterals is established. These monuments are located on the structure and downstream from the structure. In locating and installing them, care should be taken to insure that

(1) each monument is visible from every other monument.

(2) they are located at the same elevation.

(3) they are accessible or made easily accessible.

(4) they are visible to every target on the structure.

b. Targets. The targets shall be arranged at equally spaced distances along the top of the structure. If a vertical alignment is to be performed, the targets should also be placed along the downstream face of the structure in horizontal rows at the selected elevations where measurements are to be taken.

6-20. Data Collection.

a. Performing Surveys. Surveys shall be performed at night to avoid troublesome optical distortions due to sunlight and heat radiation. The surveys shall be in accordance with the accuracy with methods established for first-order triangulation measurements as stipulated by the U.S. Coast and Geodetic Survey.

b. Measurements. Before starting a triangulation survey, the distances and angles between the primary and secondary reference monuments should be measured to check for any movement of the primary monuments. If any movement has occurred, then the primary monuments must be restored to their position prior to the movement by using the distance and angle between primary and secondary monuments of the previous survey as a reference.

c. Base Lines. Measurement of the base line can be performed either through the use of a high precision metal tape or through the use of an EDM instrument. The procedures for measurement using an EDM should be the same as those described in paragraphs 6-14 through 6-17.

(1) The measurement of the distance between the primary reference monuments at each end of the base line should be made first. The distance should be measured at least two times and the average used as the base length. Temperatures should be taken along the base line to determine the length correction when using an invar tape. The best time to conduct a survey is either at night when atmospheric distortion is not a problem or on overcast days when temperatures are fairly constant across large expanses of the terrain to be measured. If an EDM is used, both pressure and temperature readings should be taken at least at both primary reference monuments.

(2) Angles should be measured from the primary reference monument at each end of the base line to all monuments and targets in the survey. All angles should be measured at least eight times and the average used for computation purposes. Elevations should be obtained on each survey point and secondary reference monument with the primary reference monuments serving as permanent bench marks.

6-21. Data Reduction. All raw distances and angles should be recorded on field data sheets as well as the averages of these figures. Temperatures, pressures, time and date of the survey should also be included on the field data sheet.

a. Computations. All computations of data should be made by automatic data processing methods. The data should be expressed in terms of the coordinates of each target and monument as calculated from the geometric properties of the triangle. The displacements of the targets are calculated by comparison of the coordinates of the targets of successive surveys.

b. Data Representation. The displacements can be graphically represented in a manner similar to that used in Figure 6-12. By referencing all displacements to an original profile, a continued record of the shape of the structure can be maintained.

c. References. Additional information on triangulation systems are referenced in the bibliography.

6-22. Trilateration.

a. General. The most recent trend in precise measurement surveys used by the Corps of Engineers is trilateration. Since the development of EDM equipment has made distance measurement both rapid and very accurate, measurement of monument location by the determination of the lengths of the sides of a triangle has become both economical and precise.

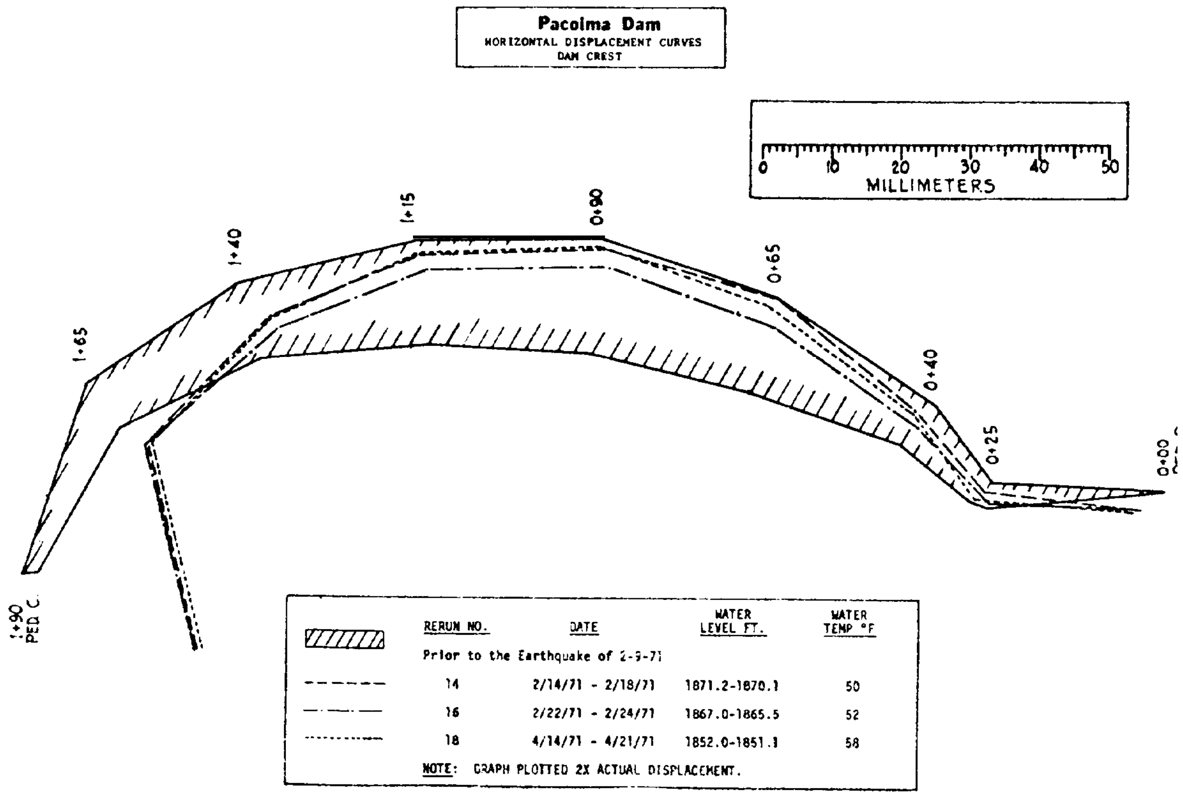


Figure 6-12. Graphic Plot of Horizontal Displacement of Dam Crest. (Prepared by CE-WES)

b. Sources of Error. Due to the preciseness of the method of measurement, sources of errors that are normally ignored in a conventional survey become major areas of inaccuracies in trilateration, and must be removed. Errors caused by changes in elevation of the line of sight, changes in pressure at different instrument locations, atmospheric refraction, and length changes due to earth curvature must be corrected before a final "corrected distance" can be recorded.

6-23. Description of the Instrument.

a. Method. The method of precise measurement of large structure movement consists of measurements in two areas. The first area is a control network of reference monuments from which all the alignment measurements are to be made and where a control length is established. The second area is the alignment markers that are to be measured for movement.

b. Control Network. The control network is set up as a stable reference from which to make measurements of movement on the structure. Since it is designed to be a static reference, the location of the monuments must be placed on stable ground a distance away from the structure sufficient to insure that the monuments will not be influenced by the forces which cause displacement of the structure. There must be at least two control monuments from which to sight on the alignment markers in order to determine their location. By using three or more control monuments additional sightings can be made on each alignment marker as an accuracy check of its location. If two dimensional movement of the structure is required, the angle of intersection of the control monuments with respect to the alignment markers should be at approximately a 900 angle to each other. A monument such as that shown in Figure 6-7 may be used.

c. Alignment Markers. The second portion of the trilateration network is the alignment markers. These points are the locations that are of interest for their movement. They are sighted from the control network and through comparison with the coordinates of previous sightings on these markers they describe the movement of the marker and consequently of the structure. They can be used to measure deflection, expansion, relative crack movement or rotation of a structure. Alignment markers similar to those shown in Figure 6-8 may be used.

d. Distance Measuring Equipment. The distance measuring equipment (EDM) required for the distance measurement consists of any one of the available EDM's on the market and their associated peripheral equipment. The minimum equipment necessary to determine the distance between monuments is an EDM meter, tripod, reflecting prism, and prism stand. The description of these instruments and their operation is contained under the Electronic Distance Measurement section of this manual, paragaphs 6-14 through 6-17.

6-24. Data Collection.

a. Initial Reading. The initial reading of the control network should be done to determine the locations of all the control monuments in the network and to assign to them a set of x and y coordinates in a chosen coordinate system. An EDM is set over each control monument, plumbed to the monument, and sighted on every other control monument in the network. The EDM is read when sighted on each monument and again read when resighted on the first monument sighted. The reason for re-sighting to the first monument is to account for any electrical drift in the EDM or changes in atmospheric conditions during the time it takes to read the network. It is a good practice to use the same control monument for the resighting as often as is possible to give a good mean distance for reference. A minimum of five measurements should be taken between each pair of monuments such that the average of the five readings can be taken as the observed distance between monuments. It is also important to measure both the temperature and atmospheric pressure at each end of each line that is measured. With the temperature and pressure known, any changes in the velocity of the light waves through the air can be determined. This process is continued until all monuments of the control network have been occupied by the EDM and sightings made to the rest of the monuments.

b. Measurement Corrections. When all the control monuments have been occupied and all the possible lines measured, the figure may be reduced to a series of triangles. Before the angles can be calculated, each line must be reduced to a chord distance on the spheroid. This reduction is necessary to apply geometric checks to figures or to calculated positions from several sets of data that agree with each other. With the measurement of all the monuments corrected and recorded, adjustments to the corrected spheroid distance can be made to account for changes in atmospheric conditions or electrical drift of the EDM.

c. Reference. The method of reading a trilateration network is a highly precise process that will yield very accurate measurement of monolith movement. For further and more detailed information on the method of operation of Electronic Distance Measuring Instruments and the procedures to conduct a trilateration survey, the reader is referred to U.S. Army Engineer Topographic Laboratories Manual ETL-0048, "The Use and Calibration of Distance Measuring Equipment for Precise Measurement of Dams," available from Engineer Topographic Laboratories, Fort Belvoir, VA 22060.

6-25. Data Reduction. With all the data collected, the distances are used to establish a coordinate system in which each reference monument, and alignment marker is assigned a coordinate. The coordinates are established by using conventional trigonometric relationships. By comparing the coordinates of each successive survey, differences in the location of the points establish the movement of the structure.

a. This method of small measurement movement has become one of the most accurate methods of surveys available. The accuracy and ability of the survey method depends upon the capabilities of the EDM used. Three instruments that have been tested by the Government and provide the high capabilities necessary for this type of survey are the Keuffel and Esser Ranger IV, the Tellurometer MA100, and the Hewlett Packard HP3808.

LASER ALIGNMENT DATA SHEET

PROJECT ____________________

ALIGNMENT SITE: ____________________

DATE: __________ TIME: __________ TEMP: __________

ATMOSPHERIC CONDITIONS: ____________________

REMARKS: ____________________

DISTANCE BETWEEN FIRST AND LAST MONUMENT ______ FT.

ADJUSTMENT = [DIFFERENCE BETWEEN FIRST & LAST RAW READING] • [PERCENTAGE OF TOTAL DISTANCE]

MONUMENT NUMBER	RAW READING	ADJUSTMENT	ADJUSTED READING	MISALIGNMENT

(Prepared by WES)

________________ PROJECT

FIELD READING SHEET–PRECISE ALIGNMENT MEASUREMENTS

SURVEY STARTED ________________

AIR TEMP. ________________ RESERVOIR ELEV. ________________ TW ELEV. ________________

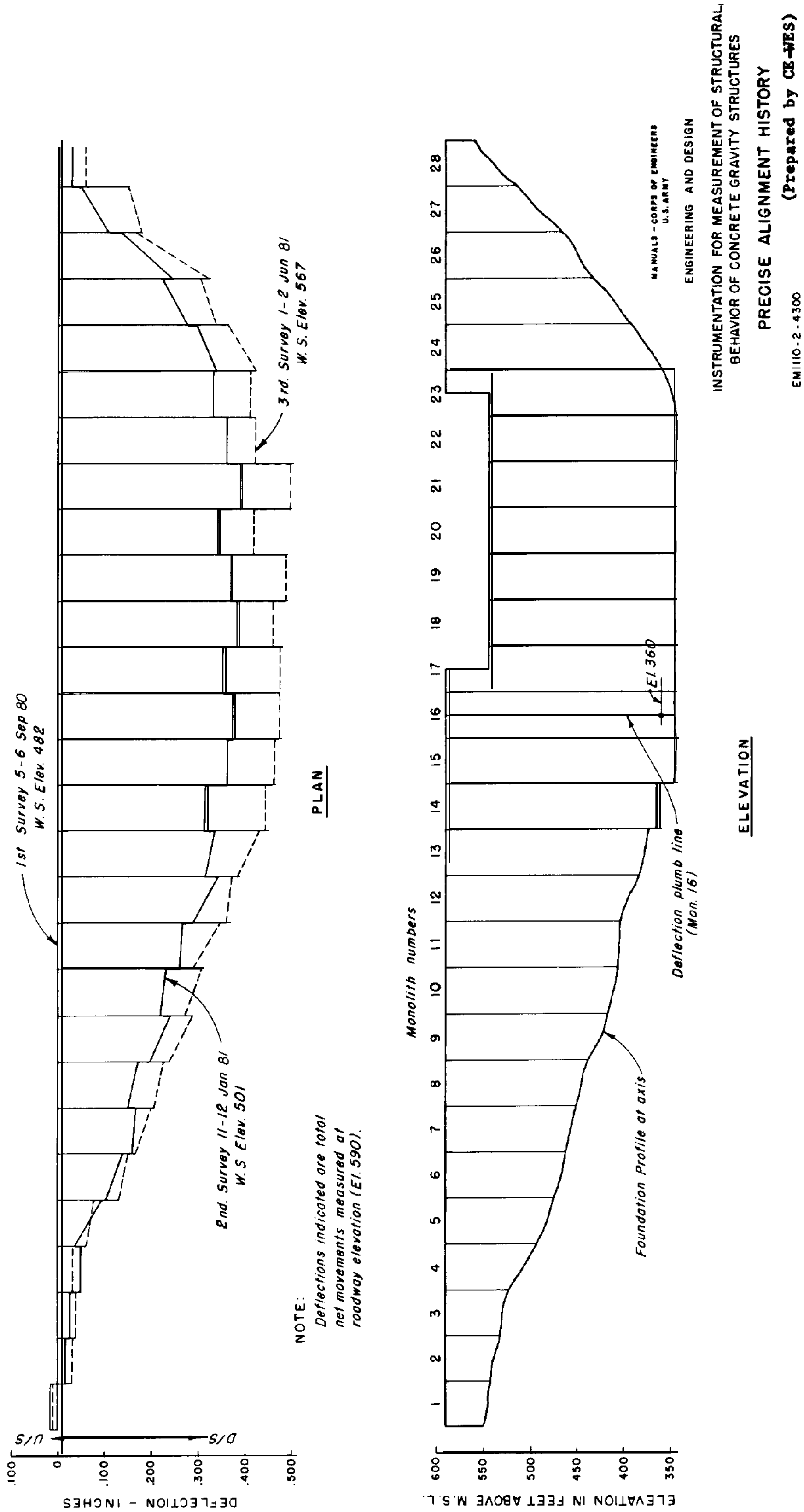
SURVEY COMPLETED ________________

AIR TEMP. ________________ RESERVOIR ELEV. ________________ TW ELEV. ________________

REMARKS ________________

MON.	PLUG NO.	TELESCOPE ERECT				TELESCOPE INVERTED				MEAN READING
		FROM RIGHT	FROM LEFT	FROM RIGHT	FROM LEFT	FROM RIGHT	FROM LEFT	FROM RIGHT	FROM LEFT	

(Prepared by WES)


INSTRUMENTATION FOR MEASUREMENT OF STRUCTURAL BEHAVIOR OF CONCRETE GRAVITY STRUCTURES
MANUALS - CORPS OF ENGINEERS U.S. ARMY
ENGINEERING AND DESIGN
PRECISE ALIGNMENT HISTORY
(Prepared by CE-WES)
EM1110-2-4300
PLAN
ELEVATION
1st Survey 5-6 Sep 80 W.S. Elev. 482
2nd Survey 11-12 Jan 81 W.S Elev. 501
3rd. Survey 1-2 Jun 81 W.S. Elev. 567
NOTE: Deflections indicated are total net movements measured at roadway elevation (El. 590).
U/S
D/S
DEFLECTION - INCHES
.100
0
.100
.200
.300
.400
.500
Monolith numbers
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
El. 360
Deflection plumb line (Mon. 16)
Foundation Profile at axis
ELEVATION IN FEET ABOVE M.S.L.
600
550
500
450
400
350